APPENDIX B. STATUS REPORT
HYDROLOGIC AND HYDRAULIC MODELS

GENERAL OVERVIEW

INTRODUCTION

This status report documents the work conducted during Phase I of the Sacramento and San Joaquin River Basins Comprehensive Study on the development of the hydrologic and hydraulic computer models. The main product components of this effort include: 1) hydrologic rainfall-runoff/routing models (i.e. HEC-1) for the subbasins downstream of the major flood control reservoirs; 2) reservoir operation (i.e. HEC-5) and system optimization models for the major flood control reservoirs in the basins; 3) hydraulic models (i.e. UNET) for the mainstem and tributary watercourses; and 4) data collection efforts to support model development. The model development effort was completely funded by the Federal government during Phase I of the Comprehensive Study.

Initial efforts conducted to support the models included development of the Hydrologic Engineering Management Plan (HEMP). This plan includes details concerning the project background, purpose, and the scope of work for this effort, and the Quality Control Plan (QCP) which quantifies the QC process used during model development and calibration. Both documents govern the overall modeling effort.

In general, model development efforts for the Sacramento River basin are ahead of those for the San Joaquin River basin. This difference is mostly attributable to familiarity with the Sacramento River system, readily available "model fragments" (i.e. HEC-1 & UNET) from previous studies conducted for the Sacramento River basin, and readily available topographic data for the Sacramento River basin. However, model development and use of each of the basin models should be equalized during the early part of Phase II of the Comprehensive Study.

Currently, the rainfall-runoff models are limited to the areas below the major reservoirs; the hydraulic models are mostly limited to the area between the levees along the watercourses. However, during the initial part of Phase II, the rainfall-runoff models will be extended and enhanced to include the entire watershed; the hydraulic models will be extended to include the overbanks and floodplains. It should be noted that model calibration is a critical, ongoing activity during model development. Several recent period-of-record events are available from the Post Flood Assessment and are being used for calibration as appropriate.

Once the models are fully functional, they will be used to establish the baseline condition and then will be used to support planning-level studies conducted during Phase II of the Comprehensive Study. Specifically, the models should focus on evaluation of various alternatives for flood reduction and ecosystem restoration throughout the study area.

In addition to the stated uses of the models during the Comprehensive Study, the base-condition hydrologic and hydraulic models could be used to compliment existing real-time discharge forecasting models to predict depths and the areal extent of flooding during future large flow events.

STUDY AREA FOR HYDROLOGIC AND HYDRAULIC MODELING

Sacramento Basin

The Sacramento River basin covers a 26,300 square mile area (at Rio Vista) about 240 miles long and up to 150 miles wide, bounded by the Sierra Nevada on the east, the Coast Range on the west, the Cascade and Trinity Mountains on the north, and the Delta-Central Sierra Area on the south (see Figure 1). Major tributaries of the Sacramento River in the study area include the Feather and American Rivers, which are tributary from the east. Numerous other smaller creeks flow into the Sacramento River from the east and west.

San Joaquin Basin

The San Joaquin River Basin lies between the crests of the Sierra Nevada and the Coast Range and extends from the northern boundary of the Tulare Lake Basin, near Fresno, to the Delta near Stockton (see Figure 2). It is drained by the San Joaquin River and its tributary system. The basin has an area of about 13,500 square miles (at the Vernalis Gage), extending about 120 miles from the northern to southern boundaries.

Although the Tulare Lake Basin is not part of the geographical focus area of the Comprehensive Study, some hydrologic modeling efforts will include this watershed because flows are exchanged between the San Joaquin and Tulare Lake Basins. During major flooding in the San Joaquin or Tulare basins, alternate routes for moving water out of the area can be investigated using the geographically expanded model.

Qualification of Status Report

One limitation to this status report is an insufficiently detailed discussion of the hydrologic and hydraulic analyses to be conducted during Phase II of the Comprehensive Study. Such a detailed discussion is well beyond the scope of this status report which focuses on model construction and data collection performed to date. An update of the HEMP should address details which outline the study approach, methodology, and types of required analyses and results for the modeling effort during Phase II.

This report does not include documentation of the development and analysis of hydrologic data (e.g. frequency curves, synthetic hydrographs) conducted to support the Post Flood Assessment, which is a separate document. Refer to that document for details concerning the regulated flood flow frequency analyses.

Although development of hydrologic data is not technically a part of model development, it is nonetheless critical to the success of the modeling effort. Therefore, a significant effort will be conducted during Phase II of the Comprehensive Study to develop additional frequency curves, n-year synthetic hydrographs, balanced hydrographs, as necessary to support delineation of the base condition and to support the analyses of alternative measures.

The Mokelumne, Cosumnes, and Calaveras Rivers are currently not included in any of the model development or data collection efforts discussed herein. These watercourses drain directly to the Delta and are treated as separable from the Sacramento and San Joaquin River systems.

DEVELOPMENT OF RAINFALL/RUNOFF (HEC-1) MODEL

GENERAL

Construction is underway for HEC-1 rainfall-runoff and hydrologic routing models for the Sacramento and San Joaquin River systems. Parts of these models are very complex. The current version of HEC-HMS does not support all the features of HEC-1 used in the existing HEC-1 model for the Sacramento River basin. The HEC-1 model will not be converted to HEC-HMS until it can be converted intact. The models developed to this point do not limit future additions and changes.

The Sacramento HEC-1 model ends downstream at two locations: the Sacramento River at Isleton, and the Yolo Bypass at the Lisbon gage. The mainstem Sacramento River below Shasta Lake, all the major tributaries below the flood control reservoirs, and the uncontrolled foothill and valley floor drainages have been completed and added to the model.

The San Joaquin River HEC-1 model, with a downstream location at the Vernalis gage, is still under construction. Rainfall-runoff components for the mainstem San Joaquin and nearly all of the major tributaries below the foothill flood control reservoirs have been completed and added to the model. Reservoir outflows for historic events are included to implicitly model the areas above the reservoirs. Some valley areas remain to be added during Phase II. In addition, during Phase II, the model will be extended down to the Stockton Deep Water Ship Channel; the Tulare Basin will also be included.

SACRAMENTO RIVER BASIN

Model Development for Phase I

A comprehensive HEC-1 Rainfall-runoff and routing model for the Sacramento River system is under construction. The mainstem Sacramento River below Shasta Lake, all major tributaries below the flood control reservoirs or USGS gaging stations, and the uncontrolled tributaries arising in the Sierra Nevada and Coast Ranges have been completed and added to the model.

The model covers the Sacramento River system down to the end points, Yolo Bypass at Lisbon gage and Sacramento River at Isleton. Models of the mainstem and most major tributaries are derived from previously completed models. Models for additional subareas have been developed for the Comprehensive Study. At the present time, the current release (version 1.0) of the Hydrologic Modeling System (HMS) does not support all the options used in the current HEC-1 model. Therefore, co-development of the model using HMS has been postponed until this capability exists. Figures 3 and 4 represent a schematic diagram of the model at the end of Phase I. This schematic diagram differs from the schematic diagram for the Sacramento River Basin HEC-5 model (shown as Figure 7) since the HEC-1 model requires greater resolution to include index points used for the UNET hydraulic routings.

Watershed Boundary Delineation

Watershed boundaries for all major foothill reservoirs in the Sierra Nevada have previously been completed and the corresponding drainage basins have been incorporated into the model. All major and most minor tributaries for the Coast Range and Sierra Nevada had been previously completed and were added to the model. Thus far, most boundary delineations are on paper maps and will be added to the GIS database cover data. The remaining boundaries have been added to the GIS database coverage.

Watershed Parameters

Unit hydrographs were developed using a variety of methods based on previous experience for the specific or adjacent watersheds. In general, unit hydrographs are based on the Los Angeles Method, using S curves previously developed specifically for valley areas. Loss rates have not yet been added to the model.

Channel Routing Parameters

Most of the routing reaches use the Muskingum or Tatum method. Most of the routing parameters were defined in previous HEC-1 models. All routing steps for the mainstem and major tributaries have been calculated and added to the model. These results are intended to serve the HEC-1 needs, as they are based on hydrologic rather than hydraulic methods.

Diversions

Diversion (weir) operations for the model are based on known system operation during historic flood events. Other event centering may cause the diversions to react differently. These differences will be developed during Phase II.

Model Development for Phase II

The endpoint of the model will be extended down to the intersection of the Sacramento River and the downstream end of the Yolo Bypass. The Colusa Drain upstream of Highway 20 will be added to the model, as will the major tributaries upstream of their reservoirs and USGS gaging stations. Representative precipitation stations will be selected for the subbasins and added to the model. Future uses for the model include real-time flood operation scenarios and development of hypothetical floods to be routed into the flood control reservoirs. For real-time operations, rainfall forecasts by the River Forecast Center will be used to route flows into upstream reservoirs to determine the effect of upstream storage on flood control reservoir operations.

SAN JOAQUIN BASIN

Model Development for Phase I

A comprehensive HEC-1 rainfall-runoff and routing model for the San Joaquin River system is under construction. Rainfall-runoff components for the mainstem San Joaquin and nearly all of the major tributaries below the foothill flood control reservoirs have been completed and added to the model.

Some valley areas, particularly to the south where channels tend to be less defined, will be added during Phase II. The model currently covers the entire San Joaquin River system from the headwaters down to the USGS Vernalis gage. Models of the mainstem and most of the major Sierra and Coast Range tributaries were derived from previously completed models. Models for additional subareas have been developed for the Comprehensive Study. Runoff from some smaller areas, each less than 25 square miles, are generally calculated as ratios of larger adjacent watersheds rather than as independent subareas. Figures 5 and 6 represent a schematic diagram of the model at the end of Phase I.

Watershed Boundary Delineation

Watershed boundaries for all major foothill reservoirs in the Sierra Nevada have previously been delineated. Watershed delineation for the nearly all the major tributaries below the foothill reservoirs have also been completed. Modeling of the local inflow to the Fresno Slough/Kings River North where the drainage is poorly defined will be added during Phase II. All major and most minor tributaries for the Coast Range above the California Aqueduct and Interstate 5 had been previously completed and have been added to the model. The remaining minor watersheds above the Aqueduct and Interstate, each less than 25 square miles, will be included as ratios to larger, adjacent watersheds.

Delineation of watershed boundaries for all mountain and upper foothill subareas were completed using GridParm. GridParm is a set of macros written for use in version 7 ARC/INFO GIS software running under Solaris 2.5 (UNIX) operating system. The source elevation data are

USGS 1 degree digital elevation model data which consist of gridded elevation points at approximately 90 meter x-y spacing. Additional boundary information is drawn from USEPA RF-1 reach files and 1:250,000 scale, USGS Hydrologic Unit Maps. Insufficient elevation resolution and errors in data sets necessitated delineation of valley and lower foothill subareas by hand on 1:24,000 and 1:100:000 scale topographic maps.

Watershed Parameters

Unit hydrographs were developed using a variety of methods based on previous experience for the specific or adjacent watersheds. In general, unit hydrographs are based on the Los Angeles Method, using S curves previously developed specifically for valley areas. Loss rates for valley areas are calculated using the SCS curve number method and hydrologic soil group when these data are available. Other valley areas and mountain areas generally employ an initial-constant loss rate. Rates for both methods are calibrated to gaged locations where available.

Channel Routing Parameters

All channel routing is done using the Muskingum method. All routing steps for the mainstem and major tributaries have been calculated and added to the model. These results are intended to serve the HEC-1 needs, since they are based on hydrologic rather than hydraulic methods. Most routing parameters came from a daily reservoir routing model constructed by the Corps in 1990. Additional intermediate steps have been added and some travel times have been changed based on subsequent work and more recent data. In general, all out-of-channel flows are routed using twice the travel time of the in-channel flows.

Diversions

Diversion operations for the model are based on known system operation during historic flood events. Other event centering may cause the diversions to react differently. These differences will be developed during Phase II.

Model Development for Phase II

The endpoint of the model will be extended down to the Stockton Deep Water Ship Channel, which will add Duck and Littlejohns Creeks and Farmington Reservoir to the model. Watershed delineation and model development for the valley floor will be completed. The Tulare Lake Basin will be added to the model. Watersheds upstream of the flood control reservoirs will be added to the model for real-time flood operation scenarios and for the development of hypothetical floods.

RESERVOIR SYSTEM ANALYSIS

Under the guidance of the Corps' Sacramento District, the Hydrologic Engineering Center (HEC) developed flow data and reservoir models for the first phase of the Comprehensive Study. The

objective is to provide simulation and optimization reservoir system models for the water control analyses of the Sacramento River Basin and the San Joaquin River Basin, including the Tulare Lake Basin. HEC developed system models and performed preliminary analysis of existing reservoir operations using data from recent flood events. The reservoir analysis involves developing modeling flow data, channel routing criteria, and reservoir system data for the application of HEC-5 and a Linear Flood Control Program. The models developed to this point do not limit future additions or changes.

SYSTEM FLOW DATA AND CHANNEL ROUTING

The original plan was to develop flow data for the 1983, 1986, 1995, and 1997 floods for all reservoirs and key channel locations in the two basins. Additionally, the data were to be developed consistently for all floods so that all model locations would have flow data for each event.

As data development proceeded, it became clear that the data were not as available as originally conceived. Problems existed in the quality and completeness of the data for all four floods. It became apparent that many agencies did not maintain short period data prior to the mid-1990's. After several meetings, it was agreed that the number of model locations would be reduced to the major flood control reservoirs and key operational locations. The system diagrams for modeling the Sacramento and San Joaquin River basins are shown in Figures 7 and 8, respectively. The flow-data development was shifted to the most recent events because the data were of better quality and more complete. The conclusion was to develop flow data for the 1995 and 1997 floods in an hourly time interval.

Sacramento District provided reservoir inflow and outflow, reservoir pool elevations, and observed flow, and/or stage data at the key model locations for the 1995 and 1997 flood events. HEC developed the flow data and associated routing criteria for the channel reaches, using the Muskingum Routing Method. Upstream observed flows are routed to the next location and the differences between upstream-routed and downstream-observed flows are computed to estimate the incremental-local flow. This resulting local flow is then used in the reservoir models.

Presently, the local flows have been computed for the 1995 and 1997 floods in the Sacramento River basin. Table 1 shows the model locations and the method used to develop the flow. Table 2 shows the estimated Muskingum Routing Coefficients used for incremental-flow computation. Routing coefficients were estimated from the UNET river routing results, where available, and by estimation of travel times from observed hydrographs where no hydraulic models were available. The reach numbers shown in Table 2 are also shown in the Sacramento Basin

Diagram in Figure 7. Similar data for the San Joaquin basin and a task report have been provided by the contractor.

The flow data at several locations produced negative local-incremental flow for both 1995 and 1997 events. Negative local flow is derived whenever the upstream-routed flow is greater than the downstream-observed. There are several sources for these apparent errors. During the 1997

flood, levee breaks around Yuba City caused flow losses. However, there are negative values in the same reaches for the 1995 flood. During these flood events, there are numerous sources of error in the estimated flow, and when the difference is taken between two hydrographs the errors may be larger than the computed differences. At some locations (e.g., Gridley) the sum of the computed locals averaged to near zero, so the local flow was set to zero. At other locations, e.g., Fremont/Verona, the negative incremental-local flow values were set to zero. In both cases, the resulting incremental-flow hydrographs will not route to match the "observed" hydrographs. Similar problems are expected in the San Joaquin flow data.

Although the derived flow data could be processed further to produce a "better looking" set of local flow data, the current data are considered sufficient for the Phase I modeling effort since the hydraulic model will eventually be used for the final channel routing. The results from the hydrologic modeling of these flood events will produce a more consistent and complete estimate for the local runoff and may be a preferable data set to use for future phases of reservoir modeling.

SACRAMENTO BASIN HEC-5 MODEL

The Sacramento Basin Model contains the five major reservoirs in the system: Shasta, Black Butte, Oroville, New Bullards Bar, and Folsom. The Sacramento Basin schematic, Figure 7, shows the key model locations. A preliminary HEC-5 data model is being developed. Presently, the model is being verified by processing the reservoir inflows with specified outflows. Model calibration for historic operation will be the next step.

The developed flow data for the basin have been completed and model calibration is ongoing.

SAN JOAQUIN RIVER AND TULARE LAKE BASINS MODEL

The San Joaquin and Tulare Lake basins are considerably more complicated than the Sacramento Basin. As shown in the Figure 8 diagram, there are flow transfers between tributaries, along with the downstream channel system. A total of 13 reservoirs are modeled; however, the HEC-5 data shows 18 reservoirs because "dummy" reservoirs were required to bring tributary flows into the system where there was no reservoir and to model multiple diversions for one location. HEC-5 only supports one diversion from a model location and each tributary must start with a reservoir.

Model verification is being performed with specified reservoir inflow and outflow. When the developed flow data and channel routing coefficients are provided by the contractor, HEC will begin the calibration process. The model development is expected to be complete by the end of March 1999.

SYSTEM OPTIMIZATION MODELS

Linear/mixed integer programming models are being developed for the Sacramento and San Joaquin River basins. These models will use the same system configuration and input data as the HEC-5 simulation models. Unlike the HEC-5 models, the purpose of which is to evaluate the performance of specified operating policies, the purpose of the optimization models is to

prescribe operating policies, given system operating objectives and constraints. Thus, the optimization results can provide insights to revised operating policies and the potential benefits of coordinated reservoir operation.

In general, an optimization model consists of a set of decision variables, an objective function, and a set of constraint equations. In the flood control optimization models, the decision variables are simply the reservoir releases in each time period. Channel flows and weir spills are then calculated as functions of reservoir releases and incremental inflows. (Weir operation is assumed to follow a specified policy.) The objective function is a summation of penalty functions, one for each control point and each time period, which provide a measure of the cost of deviating from storage, release, or flow targets. Penalties for excess channel flows are based on available flood damage data. Penalties for deviations from target reservoir storage levels are essentially calibration parameters, used to capture the risk aversion of the operators to excessively low or high storage levels. Penalties are also assessed for excessive changes in reservoir releases from one period to the next. The model constraints include mass balance constraints at each reservoir and control point, storage-outflow capacity relationships, and channel-weir flow relationships. Due to a number of non-convex relationships, a set of logical (0-1) variables and constraints is also needed to ensure that model solutions are realistic.

The optimization models for the Sacramento and San Joaquin basin systems have been validated by checking that historical inflows and releases lead to flows and storage levels which are reasonably close to historical values. Penalties for excessive flows are being derived based on economic flood damage data. Model calibration will entail the adjustment of storage penalties so that the optimization results closely match observed values for the 1995 and 1997 flood events. The models can then be used with historical or hypothetical flow data to assess the potential benefits of coordinated reservoir operation. This application will be demonstrated in the Final Report.

Due to the inclusion of a large number of 0-1 variables, the optimization models are difficult to solve in a timely manner. As such, it may not be possible to consider a 1-hour time step. Efforts are underway to improve computational efficiency so that versions of the models with 3-hour time steps can be solved within one hour.

Table 1. Sacramento River Incremental Inflow Determination

Location	Method
Shasta Dam and Lake	Hourly data were provided by the Sacramento District for the 1997 event and most of the 1995; we derived hourly inflow from daily inflows (provided by district) using the DSSMATH TTSR function for 3/8/95 0100 to 3/9/95 2400.
Black Butte Dam and Lake	Provided by Sacramento District
Oroville Dam and Lake	Provided by Sacramento District
New Bullards Bar Dam and Lake	Hourly data were provided by the Sacramento District for the '97 event; we derived hourly inflow from daily inflows (provided by district) using the DSSMATH TTSR function for the 1995 event.
Folsom Dam and Lake	Provided by Sacramento District
Bend Bridge	We subtracted the routed Shasta outflow hydrograph from the observed hydrograph at Bend Bridge.
Vina-Woodson Bridge	We subtracted the routed Bend Bridge hydrograph from the observed hydrograph at Vina-Woodson Bridge.
Ord Ferry	The East Bank Overflow (EBO) at Ord Ferry was determined using the Sacramento River flow at Ord Ferry vs. EBO relationship provided by HEC. We determined the total flow at Ord Ferry by summing the routed hydrograph from Vina Woodson, the routed Black Butte Dam release, and an estimated incremental inflow. The EBO was calculated using this flow. Then we subtracted the EBO from the total flow at Ord Ferry and routed the resulting hydrograph down to Butte City. The estimated incremental inflow was adjusted until these two hydrographs matched. Some small negative incrementals were changed to zero.
Butte Slough at Meridian	We subtracted the routed weir spill hydrographs (East Bank Overflow, Moulton Weir spill, and Colusa Weir spill) from the observed hydrograph at Meridian.
Gridley	We subtracted the routed Oroville reservoir release hydrograph from the observed hydrograph at Gridley. Many negative incrementals were found, but the sum of the computed incrementals at Gridley was approximately zero. Therefore, there will be no incremental inflows at Gridley.
Yuba City	The only observed data available at Yuba City were stage data. Therefore, we developed a rating curve at Yuba City using stage and flow output from the Sacramento District's UNET model. We determined the incremental flow at Yuba City by subtracting the routed Gridley hydrograph from the "computed" observed hydrograph for Yuba City. Small negative incrementals were changed to zero.
Marysville	We subtracted the routed New Bullards Bar Reservoir outflow hydrograph from the observed hydrograph at Marysville. Hourly data was provided for the 1997 event; we derived the hourly flow hydrograph at Marysville from daily flows using the DSSMATH TTSR function for the 1995 event.
Nicolaus	We will use an incremental inflow at Nicolaus equal to the flow on the Bear River at Wheatland routed down to the confluence with the Feather River.
Fremont/Verona	We determined the total flow in the system at Fremont/Verona by adding the observed Fremont Weir spill hydrograph to the observed hydrograph at Verona. We determined the incremental flow by subtracting the routed Wilkins Slough, Tisdale Weir spill, Meridian, and Nicolaus hydrographs from this total flow hydrograph at Fremont/Verona. Significant negative incrementals were change to zero for the 1995 event and minor negative incrementals were change to zero for the 1997 event.

Table 1. Sacramento River Incremental Inflow Determination

Location	Method
Colusa Drain	First, we determined the total incremental inflow at Woodland by subtracting the routed Fremont Weir spill hydrograph from the observed hydrograph at Woodland. The Colusa Drain incremental inflow was determined by subtracting the observed Cache Creek hydrograph from the total incremental inflow at Woodland.
Woodland	The Woodland incremental inflow is equal to the routed hydrograph for Cache Creek at Yolo.
Lisbon	Only stage data were provided at Lisbon. We developed a rating at Lisbon using stage and flow output from the Sacramento District's UNET model. We determined the incremental flow at Woodland by subtracting the routed Woodland and Sacramento Weir spill hydrographs from the "computed" observed hydrograph for Lisbon. Small negative incrementals were changed to zero for both events.

Table 2 lists the Muskingum routing parameters and identifies the method in which they were determined. The routing parameters are all based on a one-hour time-step.

We used one of the following methods to determine K and X:

1.   K and X were determined by following the method outlined in EM 1110-1417. In this method, K is estimated as the interval between similar points on the inflow and outflow hydrographs. Then, X is obtained through trial and error.

2.   In cases where the incremental inflow was too large to allow a reasonable estimation of K and X using method 1, and where appropriate information was available from the Sacramento District's UNET model, K was estimated as:

$$K ' \frac{L}{V_w}$$

where: L = length of reach and V_w = flood wave velocity.
X was estimated using the equation:

$$X ' \frac{1}{2} - 1 \ \& \ \frac{Q_o}{B \ S_o \ c \ ?X} \ i$$

where: Q_o = reference flow from the inflow hydrograph, c = flood wave speed,
        S_o = friction slope or bed slope, B = top width of the flow area, and
        $?X$ = length of the routing subreach (EM 1110-2-1417).

If only velocity information was available from the UNET model, X was estimated as 0.2.

3.   In cases where the incremental inflow was too large to allow a reasonable estimation of K and X using method 1 and appropriate data were not available from the UNET model, X

was estimated as 0.2 and K was estimated using an assumed flood wave velocity between 3-5 ft/s.

To ensure that the Muskingum routing coefficients were positive for each reach, the number of steps was calculated using the equation:

$$\#Steps = \frac{K}{\Delta t}$$

Since $\Delta t = 1$ hour, # STEPS = K.

Table 2. Muskingum Routing Parameters for the Sacramento River System

Reach	From	To	X	K (hrs)	Steps	Method
1	Shasta Dam & Lake	Bend Bridge	0.1	12.	12	1
2	Bend Bridge	Vina-Woodson	0.2	9.	9	1
3	Vina-Woodson	Ord Ferry	0.15	17.5	17	1
4	Ord Ferry	Butte City	0.2	1.5	1	1
5	Butte City	Moulton Weir	0.2	5	5	1
6	Moulton Weir	Colusa Weir	0.2	14	14	1
8	Colusa Weir	Tisdale Weir	0.25	6	6	2
10	Tisdale Weir	Fremont Weir / Verona	0.38	13	13	2
11	Black Butte Dam & Lake	Ord Ferry	0.2	11	11	1
12	Ord Ferry	Butte Slough nr Meridian	0.1	28	28	1
13	Moulton Weir	Butte Slough nr Meridian	0.1	19	19	1
14	Colusa Weir	Butte Slough nr Meridian	0.1	16	16	1
15	Butte Slough nr Meridian	Sutter Bypass RD 1500	0.2	16	16	3
16	Tisdale Weir	Sutter Bypass RD 1500	0.2	11	11	3
17	Sutter Bypass RD 1500	Fremont Weir / Verona	0.2	1	1	3
18	Oroville Reservoir	Gridley	0.2	8	8	1
19	Gridley	Yuba City/ Junction	0.17	18	18	2
20	Yuba City/ Junction	Nicolaus	0.35	4	4	2
21	New Bullards Bar Dam & Lake	Marysville/ Junction	0.15	5	5	1
23	Nicolaus	Fremont Weir / Verona	0.2	4	4	2
24	Fremont Weir / Verona	Colusa Drain	0.2	4	4	2
25	Fremont Weir / Verona	Sacramento Weir	0.2	6	6	2
26	Colusa Drain	Woodland/ I-80	0.2	2	2	2
27	Woodland/ I-80	Lisbon	0.2	7	7	2
28	Folsom Dam & Lake	Fair Oaks	0.4	1	1	1
29	Fair Oaks	H Street	0.2	3	3	2
30	H Street	Junction/ Sacramento Weir	0.2	2	2	2
31	Junction/ Sacramento Weir	Freeport	0.2	5	5	2
33	Freeport	Rio Vista	0.2	8	8	2
34	Lisbon	Rio Vista	0.2	16	16	2

HYDRAULIC MODEL (UNET) DEVELOPMENT

GENERAL

This section documents development of the hydraulic models for the Sacramento and San Joaquin River basins. Model development has been focused on the one-dimensional, unsteady model UNET. UNET simulates unsteady flow through a network of channels, weirs, bypasses and storage ponds. Two UNET models are currently being developed, one for the Sacramento River system and one for the San Joaquin River system. The UNET models are being constructed to allow modeling of both flood flow and low flow conditions. In addition, an HEC-RAS steady state model has been developed in parallel with construction of the Sacramento River UNET model.

To date, model construction for both basins has consisted of developing river alignments, developing cross sectional geometry from the topographic and hydrographic data, and constructing functional UNET models. For Phase I, model development was limited to the area between the levees. That is, the models will simulate flow in the main river channels but they do not currently have the capacity to simulate overbank or floodplain flow. This capability will be incorporated into the models during Phase II of the Comprehensive Study.

In general, model development for the Sacramento River basin model has proceeded well ahead of development of the San Joaquin River basin model for two reasons: 1) the topographic data for the Sacramento River basin was readily available (discussed in further detail under "Data Collection"); and 2) a large amount of modeling and study has previously been performed on the Sacramento River basin by the District, thus making readily available existing model "fragments" as well as in-depth experience with the river system. Specific watercourse reaches included in the models are discussed in detail in the sections below on the Sacramento River and San Joaquin River Basin.

SACRAMENTO RIVER BASIN

Description. Construction of the Sacramento River Flood Control Project (SRFCP) began in 1918. Various project components were completed between 1952 and 1958, and the active portion was completed in 1968. The project consists of a comprehensive system of levees, weirs, gates, pumping plants, leveed bypass floodways and overbank floodway areas.

The project includes approximately 1,300 miles of levees which provide protection to about 800,000 acres of agricultural lands; the cities of Colusa, Gridley, Live Oak, Yuba City, Marysville, Sacramento, West Sacramento, Courtland, Isleton, Rio Vista and numerous smaller communities; transcontinental railroads; feeder railroads; airport facilities; and many Federal, State, and county highways. Billions of dollars in flood damages have been prevented since the project was completed.

During major flood events, upstream reservoirs in the Sacramento, Feather, and American River basins intercept and store initial surges of runoff and provide a means of regulating floodflow releases to downstream leveed streams, channels, and bypasses. In order to achieve the full benefits of the reservoirs, specific downstream channel capacities must be maintained. Reservoir operation is coordinated not only among various storage projects but also with downstream channel and floodway carrying capacities.

Model Status. As of April 1, 1999, the Sacramento River model will cover all locations shown in Table 3. Ongoing efforts will include flood flow calibration of the model. The January 1997 flood event is being used to calibrate the model. There are many locations throughout the Sacramento River basin that have observed stage and flow data for the January 1997 flood event. Low flow calibration will be conducted in a later phase.

Model Extent. The specific watercourses which have been included in the model are listed below in Table 3 and are illustrated on Figure 9. This list shows the current model extent and does not limit future additions to the model.

TABLE 3
REACHES INCLUDED IN SACRAMENTO RIVER MODEL

Watercourse	Downstream Boundary	Upstream Boundary	Distance (mi)
Mainstem			
Sacramento River	Collinsville (RM 0)	Woodson Bridge (RM 219)	219
Tributaries & Bypasses			
Butte Basin	Sutter Bypass	Sacramento River	8
Sutter Bypass	Sacramento River	Butte Basin	30
Wadsworth Canal	Sutter Bypass	Interceptor	4
Tisdale Bypass	Sutter Bypass	Sacramento River	5
Feather River	Sacramento River (RM 0)	Gridley (RM 51)	51
Yuba River	Feather River	Daguerre Pt. Dam	11
Bear River	Feather River	Wheatland	11
Dry Creek	Bear River	River Mile 5	5
Yankee Slough	Bear River	River Mile 6	6
WP Intercept Canal	Bear River	River Mile 5	5
Yolo Bypass	Cache Slough	Sacramento River	41

TABLE 3
REACHES INCLUDED IN SACRAMENTO RIVER MODEL

Watercourse	Downstream Boundary	Upstream Boundary	Distance (mi)
Knights Landing Ridge Cut	Yolo Bypass	Colusa Basin Drain	7
Sacramento Bypass	Yolo Bypass	Sacramento River	2
Natomas Cross Canal	Sacramento River	Pleasant Grove Canal	5
Natomas Cross Canal Tribs	Natomas Cross Canal	Various Locations	5
American River	Sacramento River	Nimbus Dam	21
Natomas East Main Drain	Sacramento River	Sankey Road	15
Deep Water Channel	Cache Slough	Turning Basin	20
Cache Slough	Yolo Bypass	Hastings Cut	8
Lindsey Slough	Cache Slough	State Route 113	7
Distributaries			
Steamboat Slough	Cache Slough	Sacramento River	11
Sutter Slough	Steamboat Slough	Sacramento River	7
Georgiana Slough	Mokelumne River	Sacramento River	11
Miner Slough	Cache Slough	Sutter Slough	8
Threemile Slough	San Joaquin River	Sacramento River	3
		Total Model Length (mi)	526

Detailed topography is not currently available for the Bear River tributaries (Dry Creek, Yankee Slough, WP Intercept Canal), Cross Canal tributaries and for Feather River from Gridley to the Bear River, approximately a 37-mile reach. Current topography in the UNET model for the Bear River and Cross canal tributaries was generated from USGS 7.5 minute quad maps. On the Feather River, topography between the Bear River and the Yuba River consists of cross-sections surveyed by the DWR in 1996. Above the Yuba River, data consist of various dated cross-sectional data.

In addition to the above reaches, the UNET model includes the Moulton, Colusa, Tisdale, Fremont, and Sacramento weirs.

SAN JOAQUIN RIVER BASIN

Description. Flood control facilities in the San Joaquin River Basin consist of a complicated, interconnected series of natural, semi-modified, and constructed channels, with and without levees. In addition, a number of canals have been constructed throughout the valley with the

primary function of water supply, but these canals may also be used for diverting and/or controlling flood runoff. Along the east side of the valley, multipurpose reservoirs are located primarily in the foothills and provide various levels of flood protection.

Major tributary streams to the San Joaquin River mainstem include, from north to south, the Cosumnes, Mokelumne, Calaveras, Stanislaus, Tuolumne, and Merced Rivers. These streams, along with the San Joaquin River, contribute the major portion of the surface inflow to the San Joaquin basin. Minor streams on the east side of the valley include the Fresno and Chowchilla Rivers, and Burns, Bear, Owens, and Mariposa Creeks. Panoche, Little Panoche, Los Banos, San Luis, Orestimba, and Del Puerto Creeks comprise the minor streams on the west side. These west side streams contribute very little to the runoff of the San Joaquin River. Numerous other small foothill channels carry water only during intense storms.

During high runoff periods, a distributary channel of the Kings River (called James Bypass) discharges water into the San Joaquin River near Mendota. In addition, flood water is diverted to the San Joaquin River from Big Dry Creek Reservoir near Fresno. Flows from the rivers and creeks are significantly reduced by storage, diversions, and channel seepage losses as they cross the valley floor so that only a portion of the water at the foothill line reaches the San Joaquin River.

As discussed at the beginning of this report, the Mokelumne, Cosumnes, and Calaveras Rivers are currently not included in any of the model development or data collection efforts discussed herein. These watercourses drain directly to the Delta and are treated as separable from the Sacramento and San Joaquin River systems.

Model Status. As of April 1, 1999, model development for the San Joaquin River system was limited due to the time required for obtaining detailed topographic and hydrographic mapping data. As discussed below in the section, Data Collection, a significant survey effort was conducted during Phase I to obtain as much geometric data as possible along the San Joaquin River mainstem and main tributary and distributary watercourses. The downstream segment of mapping data was not available until late October 1998; data for the most upstream reach became available in late February 1999. In general, model development has consisted of putting the cross sectional geometry into the model and coding in the pertinent job control and data necessary to run flow through the model. Model "clean-up" and calibration will occur during the initial part of Phase II of the Comprehensive Study.

Model Extent. The specific watercourses included in the model are listed below in Table 4 and are illustrated on Figure 10. This list shows the current model extent and does not limit future additions to the model. As illustrated in Figure 10, the San Joaquin River model will be extended upstream from Gravelly Ford to Friant Dam during Phase II of the Comprehensive Study.

TABLE 4

REACHES INCLUDED IN SAN JOAQUIN RIVER MODEL

Watercourse	Downstream Boundary	Upstream Boundary	Distance (mi)
Mainstem			
San Joaquin River	Stockton Deep Water Channel (RM 40)	Gravelly Ford (RM 230)	190
Tributaries, Bypasses, & Parallel Watercourses			
Eastside Bypass	Deep Slough	San Joaquin River @ Bifurcation Structure	41
Fresno Slough	San Joaquin River	James Road	12
James Bypass	Fresno Slough	James Road	2
Fresno River	Eastside Bypass	Road 18	6
Berenda Slough	Eastside Bypass	Route 152	11
Ash Slough	Eastside Bypass	Route 152	6
Mariposa Bypass	San Joaquin River	Eastside Bypass	4
Deep Slough	Bear Creek	Mariposa Bypass	6
Bear Creek	San Joaquin River	East Side Canal	7
Merced River	San Joaquin River	Route 165 (u/s end of levees)	22
Laird Slough	San Joaquin River	San Joaquin River	3
Tuolumne River	San Joaquin River	Jennings Road (u/s end of levees)	12
Stanislaus River	San Joaquin River	Route 99	13
Distributaries			
Paradise Cut	Old River	San Joaquin River	7
Old River	Tracy Boulevard	San Joaquin River	11
Middle River	Victoria Canal	Old River	12
Doughty Cut	Grant Line Canal	Old River	1
Grant Line Canal	Tracy Boulevard	Doughty Cut	1
		Total Distance (mi)	367

RELATED HYDRAULIC MODELING EFFORTS

As discussed above, the majority of the model development effort has been the construction of the UNET models for the Sacramento and San Joaquin River basins. Previous and current efforts by the District which will complement the Comprehensive Study are listed below. In addition, it is envisioned that sediment transport analyses (e.g., HEC-6) will be conducted for both river systems during Phase II of the Comprehensive Study.

Yolo Bypass RMA-2 Model. An RMA-2 model of the entire Yolo Bypass was developed to evaluate the impacts of ecosystem restoration on the capacity of the bypass. The Sacramento District is currently updating the topographic data in the RMA-2 model with the 1997 Sacramento River basin survey data. It is envisioned that this two-dimensional RMA-2 model will be used to obtain insight into the functioning of the Sacramento River system, in addition to information gained from the UNET modeling.

Sacramento River - Road 29. An RMA-2 model of the Sacramento River, and adjoining Butte Basin, from Sacramento River mile 195 to Sacramento River mile 174 was developed under contract. This model was developed to analyze possible effects on the Sacramento River Flood Control Project which may result from changes in river meanders, bank protection sites, Murphy Slough Plug, and Road 29 reconstruction. It is envisioned that this two-dimensional RMA-2 model will be used to obtain insight into the functioning of the Sacramento River system, in addition to information from the UNET modeling.

Stanislaus River FEMA Mapping. FEMA has requested that the Sacramento District develop floodplain mapping along the upper Stanislaus River (RM 12 to 47). It is envisioned that the HEC-RAS model will be incorporated into the San Joaquin River system UNET model during Phase II of the Comprehensive Study.

Tuolumne River FEMA Mapping. FEMA has requested that the Sacramento District develop floodplain mapping along the upper Tuolumne River (RM 11 to 22). Similar to the Stanislaus River, it is envisioned that the HEC-RAS model will be incorporated into the San Joaquin River system UNET model during Phase II of the Comprehensive Study.

<div align="center">

DATA COLLECTION

</div>

GENERAL

Data collection comprises a significant part of the hydrologic and hydraulic model development. Required data from these efforts include hydrologic data such as stream flow and stage records, tide data, and topographic data. The following sections document the data collection to date. Additional flow and tide data will be required as well as topographic data for the overbank areas along the mainstem watercourses.

STREAM GAGE DATA

In support of hydrologic and hydraulic model development for the Comprehensive Study, the Water Management Section of the Sacramento District, has compiled an extensive database of hydrologic records for system reservoirs and stream gages in the Sacramento and San Joaquin River basins. Both daily and hourly data were gathered for major California floods at over 70 points of interest throughout the basins. Data consist of: 1) <u>Reservoir Projects</u> - hourly and mean

daily inflow and outflow, hourly and end-of-day storage, hourly and end-of-day elevation, and hourly and end-of-day top of conservation pool storage; and 2) <u>Stream Gages</u> - hourly and mean daily flow, and hourly stage. Currently, the periods of interest for hourly data are as follows: 1) December 26, 1996 - January 10, 1997; 2) March 8-22, 1995; 3) February 12-26, 1986; and 4) February 26 - March 12, 1983. Daily data were gathered for the complete water year encompassing each short period.

The data are stored on the Water Management modeling workstations which also maintain the period of record water control data used for District operations and studies. The data are available to HEC and other cooperators via the Internet. The data are stored in the standard Corps time series database format, Data Storage System (DSS), developed and supported by HEC.

The following text documents only the general procedures used in collection and preparation of data for individual basins. Methodology varied within each basin to accommodate the extent of gage data coverage at each point of interest.

Sacramento River Basin

The appropriate responsible agencies (e.g. USGS, DWR, USBR, local cooperators, etc.) were contacted to obtain the official records for their gages. Because of gage outages and data availability, a data completion rate of greater than 90-95 percent could not be expected. Secondary sources such as USACE or CDEC archives were used when the responsible agency could not provide information.

Screening and checking methods were established to keep track of data processing for model input. The screening process involved identifying and correcting errors, as well as estimating missing data using all available information at the gage and adjacent gages. The following describes some of the methods used to process the data:

> 1) Linear interpolation was used when only short periods of hourly or bi-hourly data were missing.

> 2) If stage data were available, rating tables were obtained (or developed) and used to translate stage to flow. In some cases, stage data exceeded the range of the rating table and were translated through extrapolation.

> 3) Hourly flow was estimated by using the flow pattern of an adjacent gage to distribute mean daily flows, if available.

> 4) A correlation was made between two stations to estimate flows using available data (this method is only appropriate where flows are not heavily regulated).

5) Computation of any missing inflow, outflow, or storage values was done for reservoir projects so that the volumes of water balanced.

6) When records had missing information at both the beginning and the end of the period, more efforts were made to complete the data at the beginning of the event than at the end. For some data where the last day or two of data are consistently missing, Water Management may consider shortening the event period.

Data collection and screening efforts also varied by water year. More detailed information is included below.

1997 and 1995. The largest data gap occurred at several of the weirs. DWR personnel provided essentially all available weir data for these years. Personnel extrapolated the rating tables for the weirs. Efforts were made to balance the estimated weir flows with actual volumes occurring within the system.

1986 and 1983. Over 75 percent of 1983 and 1986 Sacramento River Basin data available electronically has been collected. However, large data gaps remain, due to the fact that gage data are either no longer available or only available in hard copy. The 1983 and 1986 hourly data will not be used for model calibration. When only hard copy data were available, it was keypunched, carefully screened, and loaded into the DSS (HEC-Data Storage System). It may be necessary to change the 1986 event period because of the amount of hourly data missing at the beginning and the end of the defined event period.

San Joaquin River Basin

Gage records targeted for collection were specified to provide adequate data coverage of the San Joaquin mainstem, major tributaries, all reservoirs with operational flood space, and minor tributaries related to the estimation of local flow below flood control reservoirs. Efforts to locate data generally involved investigation of the following sources, until the complete record was found or the search was concluded: USACE archives, USGS and DWR electronic archives, personal communication with cooperating agencies (USGS, DWR, USBR, Irrigation Districts, Water Associations, and other local cooperators).

All data acquired underwent a screening process designed to identify and correct errant data, estimate missing data points, and assure that daily and hourly data records were in agreement. Methods used mirrored those outlined above in the Sacramento River discussion. Due to changes in the data acquisition policies of individual agencies with respect to time, discussion of screening methodology is separated by water year.

1997. The majority of required data was available directly from USACE databases. Generally, daily data were accurate and required only minor adjustments. Hourly data for reservoirs operated by the Corps were also available and accurate. Short period data for Section 7 reservoirs (the general name used for flood control projects not owned and operated by the Corps) were available in bi-hourly intervals for most time steps during the 1997 flood period. Missing bi-hourly values were estimated and complete hourly records were obtained through linear interpolation. Daily and hourly stream gage records were obtained from USGS, DWR, and USACE databases.

1995. The primary difference between WY-97 and WY-95 data was in the availability of short period data (hourly or bi-hourly) for Section 7 reservoirs. Often, no short period data (except reservoir release logs) were recorded. In these cases, inflows and storage for Section 7 projects were based on archived daily values and hourly inflow patterns from nearby Corps reservoirs, which recorded hourly data throughout the flood period. Patterned records were adjusted and smoothed until the hourly time series concurred with archived daily values.

Status Summary

For the Sacramento Basin, personnel gathered and screened short period hourly and daily data for the 1983, 1986, 1995, and 1997 flood events for the hydrologic and hydraulic model development and calibration. The 1995 and 1997 data collected are about 90 percent complete and are more than adequate for the level of H&H model development and calibration required for this study phase. These data have been made available to HEC. Processing of the data for the1983 and 1986 events continues.

For the San Joaquin River basin, acquisition and screening of hourly data have been completed for the 1995 and 1997 flood periods. Daily data for WY-97 have also been screened and posted. Daily data for WY-95 have been gathered, but most records must be screened and posted. Additionally, hourly data processing for the 1986 flood period, February 12-26, is nearing completion. These data will not be used for model construction or calibration, but will be available during system assessment and investigation of alternative flood management measures.

The February 1986 unregulated event (above the reservoirs) in the San Joaquin River Basin was larger than the March unregulated event. However, regulated flows and stages on the mainstem were greater in March. A similar situation also occurred in January 1997 on portions of the mainstem of the San Joaquin River. The largest unregulated event is desired for reservoir modeling. Additional data may need to be gathered if the larger mainstem flow and stage data are needed to better calibrate the system model.

TOPOGRAPHIC DATA

General

Topographic data is an essential part of any hydraulic modeling effort. It forms the geometric input to the UNET, HEC-RAS, HEC-6, and RMA-2 modeling. During the data investigation phase of this study personnel identified potential sources of topographic data for the study area. As discussed below, mapping for the Sacramento River system was readily available for model development. However, for the San Joaquin River system, the only source of topographic data which covered the entire study area were the USGS 7.5 minute quads. In a few cases, small unconnected segments of mapping were also identified throughout the San Joaquin River system. This mapping was previously collected for various purposes at various times and was not considered a worthwhile source of data. Therefore, given the lack of detailed up-to-date mapping, an extensive amount of topographic and hydrographic data was collected on the San Joaquin River system to support the hydraulic modeling efforts during Phase I of the Comprehensive Study.

In general, mapping for both the Sacramento and San Joaquin River systems currently is comprised of linear riverine reaches which include the main river channel between the levees, the levees, and the overbanks for a distance of approximately 300 feet landward of the levees. Future mapping efforts by the District include: 1) detailed topographic and hydrographic surveys of the Feather, Bear, and Yuba Rivers, and 2) basin-wide topographic surveys of the Sacramento and San Joaquin River systems of sufficient extent to contain the 500-year flood footprint. These data collection efforts should be conducted by the summer of 1999.

Data Storage. Early in the Comprehensive Study, it was determined that the District's capacity for data storage was insufficient to support and manage the vast amount of topographic data required for development of the hydraulic models. Therefore, the Hydraulic Design Section obtained a server-class Intergraph workstation with a storage capacity of approximately 140 GB. All topographic data, digital ortho photos, flow and tide data, documentation, and the models themselves are stored on this server. In order to promote data sharing for the Comprehensive Study, as well as other projects located within the study area, the entire District has "read-only" access to the server.

Subsidence. Area-wide land subsidence is a potential problem within the study area since the hydraulic models depend greatly on accurate geometry as well as on historic gage and high water data for calibration efforts. Although various rates and amounts of subsidence have been documented throughout the Sacramento and San Joaquin River basins as well as in the Delta, the area of greatest concern for this study is the southwestern part of the San Joaquin River basin near Mendota. Based on information researched and documented for the Arroyo Pasajero Feasibility Study, the subsidence ranges between one and six feet for the period of 1926 through 1970 for the San Joaquin River between River Miles 160 and 220.

At present, changes to the channel geometry from historic subsidence are explicitly included in the topographic data since all of the mapping is relatively recent (i.e. all mapping used for model development was collected between 1995 and 1998). As discussed, additional topographic data will be collected during 1999 which will also include the effects of historic subsidence. Since model calibration will be performed primarily using flow and stage data from the 1995 and 1997 floods, the effects of subsidence should not affect model development. In addition, since application of the models is expected to occur over the next five or so years, the effects of future subsidence should not significantly affect the model results. However, if the geometric data in the present models is used for an extended time (e.g., greater than ten years), then a program should be developed to track changes in the topographic data. If necessary, some reaches may require a new topographic survey.

The following sections provide detailed information regarding the mapping efforts conducted to date to develop the topographic data which is being used for hydraulic model construction.

Sacramento River Basin

Overview. The Sacramento District has conducted hydrographic and photogrammetric surveys of the Sacramento River Basin. The survey area consists primarily of the mainstem of the Sacramento River and includes reaches of the major tributaries, distributary sloughs, and the flood bypasses. This survey data was originally collected to support hydraulic analyses conducted for the Sacramento River Bank Protection Project (SRBPP). The data is currently being used as the geometry for development of basin-wide hydraulic modeling by the District for the Sacramento and San Joaquin River Basins Comprehensive Study.

Data collection was conducted to produce topographic mapping above and below the waterline to an accuracy suitable for development of 2-foot contours along most of the watercourses. However, along the most northern reach of the Sacramento River and throughout most of the Butte Basin overbanks, the survey was conducted with an accuracy suitable to produce 5-foot contours. The mapping is accurate vertically to one half of the contour interval.

Description of Data. The hydrographic and topographic data were developed for use in MicroStation and InRoads. The topographic data is presented as 3-dimensional contour files (i.e. *.dgn) and the planimetric data is presented in separate 3-dimensional design files (i.e. *.dgn). Along each reach of the surveyed watercourses, full digital terrain models (DTM's) were developed for the hydrography and the topography. These DTM's were produced to be used within the InRoads software (i.e. *.dtm) and may have some value in other software platforms (e.g. GIS). Along the Yolo, Sutter, Tisdale, and Sacramento Bypasses, the survey data consists of HEC-2 formatted cross sections which are based on photogrammetry suitable to produce 2-foot contours.

Data Format.

Units:	Feet
Map Scale:	1 inch = 100 feet for 2-foot contour mapping (3 foot horz accuracy)
	1 inch = 300 feet for 5-foot contour mapping (8-10 feet horz accuracy)
System:	CA State Plane Coordinate System 1983; Zone 2
Geodetic Datum:	NAD 83
Ellipsoid:	WGS84
Vertical datum:	NGVD 1929
Date of Mapping:	Most of the survey data was collected in 1997 with the exception of part of the Butte Basin which was collected in 1995.

Methodology. Above the waterline, topography was developed using standard photogrammetric mapping techniques with flight elevations above the mean terrain of 5,000 feet for the 2-foot contour mapping and 12,000 feet for the 5-foot contour mapping. All of the aerial photos taken for the survey were in black and white. Digital ortho photos have only been developed for the American River reach of the mapping.

The hydrosurvey data was collected along the watercourses with boats equipped with a dual frequency GPS receiver, fathometer, and sonar transducer. Hydrographic survey data was collected along river cross-sections oriented generally perpendicular to the channel banks, at a nominal spacing roughly equal to the average width of the main channel in the vicinity of each cross section.

Detailed Listing of Surveyed Reaches.

Sacramento River	RM 0 (Collinsville) to 218 (Vina-Woodson Bridge)
Steamboat Slough	Entire Length
Sutter Slough	Entire Length
Miner Slough	Entire Length
Georgiana Slough	Entire Length
Cache Slough	Lower End
Three Mile Slough	Entire Length
Shag, Hass, and Lindsey Sloughs	Lower Ends
American River	RM 0 (Mouth of Sac River) to RM 23 (Nimbus Dam)
Yolo, Sutter, Tisdale, & Sacramento Bypasses & Tributaries	Entire Lengths of Bypasses, Lower Ends of Tributaries
Feather River	RM 8 (Sutter Bypass) to RM 13 (Mouth of Bear River)

Butte Basin   This data consists primarily of the east overbank between
                                          the Sutter Buttes and the Vina-Woodson Bridge extending 3
                                          to 11 miles to the east of the Sacramento River

San Joaquin River Basin

Overview. The Sacramento District has conducted hydrographic and photogrammetric surveys of
the San Joaquin River Basin. The survey area consists primarily of the mainstem of the San
Joaquin River and includes reaches of the major tributaries, distributary sloughs, and the
Eastside/Chowchilla Bypass. The data was collected for use as the geometry for development of
basin-wide hydraulic modeling by the District for the Sacramento and San Joaquin River Basins
Comprehensive Study.

Data collection was conducted to produce topographic mapping above and below the waterline to
an accuracy suitable for development of 2-foot contours along the watercourses. The mapping is
accurate vertically to one half of the contour interval.

Description of Data. The hydrographic and topographic data were developed for use in
MicroStation and InRoads. The topographic data is presented as 3-dimensional contour files (i.e.
*.dgn) and the planimetric data is presented in separate 3-dimensional files (i.e. *.dgn). Along
each reach of the surveyed watercourses, full digital terrain models (DTM's) were developed for
the hydrography and the topography. These DTM's were produced to be used within the InRoads
software (i.e. *.dtm) and may have some value in other software platforms (e.g. GIS).
Additionally, black and white digital ortho photos have been developed from the aerial
photogrammetry and are being used as a background for the topography. The digital ortho photos
have a pixel size of 1-foot and a horizontal positional accuracy of one foot for areas coinciding
with the DTM's and a horizontal positional accuracy of 8 to 10 feet elsewhere.

Data Format.

Units: Feet
Map Scale: 1 inch = 100 feet for 2-foot contour mapping (3 foot horz accuracy)
System: CA State Plane Coordinate System 1983; Zone 3
Geodetic Datum: NAD 83
Ellipsoid: WGS84
Vertical datum: NGVD 1929
Date of Mapping: Summer 1998

Methodology. Above the waterline, topography was developed using standard
photogrammetric mapping techniques with flight elevations above the mean terrain of 5,000 feet
for the 2-foot contour mapping. All of the aerial photos taken for the survey were in black and
white.

The hydrosurvey data was collected along the watercourses with boats equipped with a dual frequency GPS receiver, fathometer, and sonar transducer. Hydrographic survey data was collected along river cross-sections oriented generally perpendicular to the channel banks, at a nominal spacing roughly equal to the average width of the main channel in the vicinity of each cross section.

Detailed Listing of Surveyed Reaches.

|	
San Joaquin River	RM 40 (Deep Water Ship Channel in Stockton) to RM 230 (Gravelly Ford)
Middle River	North/Victoria Canals to Old River
Old River	Tracy Boulevard to San Joaquin River
Grant Line Canal	Tracy Boulevard to Doughty Cut
Doughty Cut	Grant Line Canal to Old River
Paradise Cut	Old River to San Joaquin River
Stanislaus River	San Joaquin River to u/s of Oakdale (RM 47)
Tuolumne River	San Joaquin River to RM 12 (d/s of Hwy 99)
Laird Slough	San Joaquin River RM 87 to RM 90
Merced River	San Joaquin River to above Hwy 99
Bear Creek	San Joaquin River to East Side Canal
Deep Slough	Bear Creek to Eastside/Mariposa Bypasses
Mariposa Bypass	San Joaquin River to Eastside Bypass/Deep Slough
Eastside/Chowchilla Bypass	Deep Slough/Mariposa Bypass to San Joaquin River (RM 216)
Ash Slough	Eastside Bypass to Hwy 152
Berenda Slough	Eastside Bypass to Hwy 152
Fresno River	Eastside Bypass to Road 16
Fresno Slough	San Joaquin River to James Slough
James Slough	Fresno Slough to James Road

In addition, the Bureau of Reclamation obtained via contract a similar hydrographic and topographic survey of the San Joaquin River between Gravelly Ford (RM 230) and Friant Dam (RM 267) during August-September 1998. This survey data supports 2-foot contours. The digital ortho photos were taken in color as opposed to black and white. This survey data has the same format as discussed above, with the exception that the mapping is in Zone 4 of the CA State Plane Coordinate System.
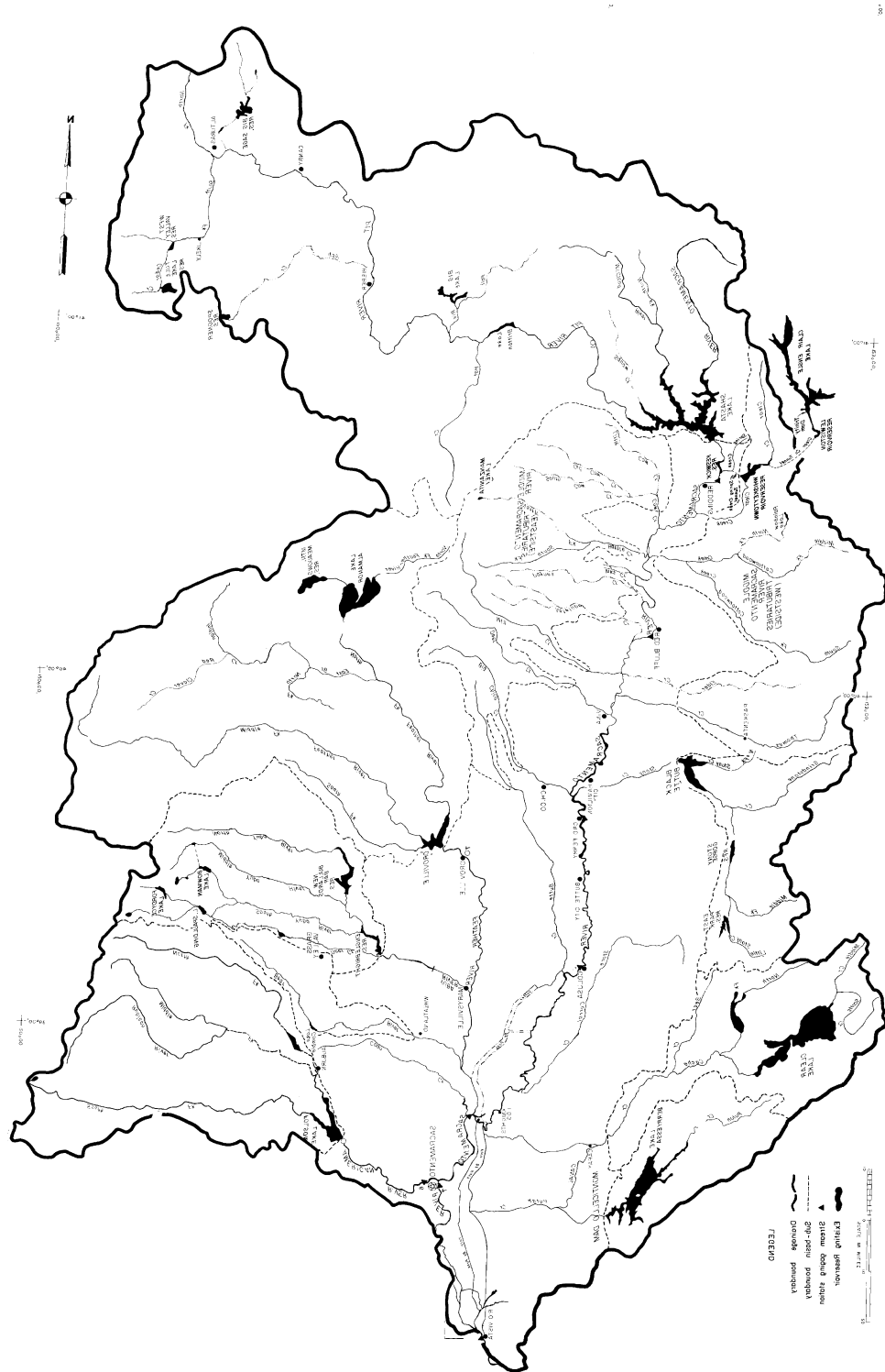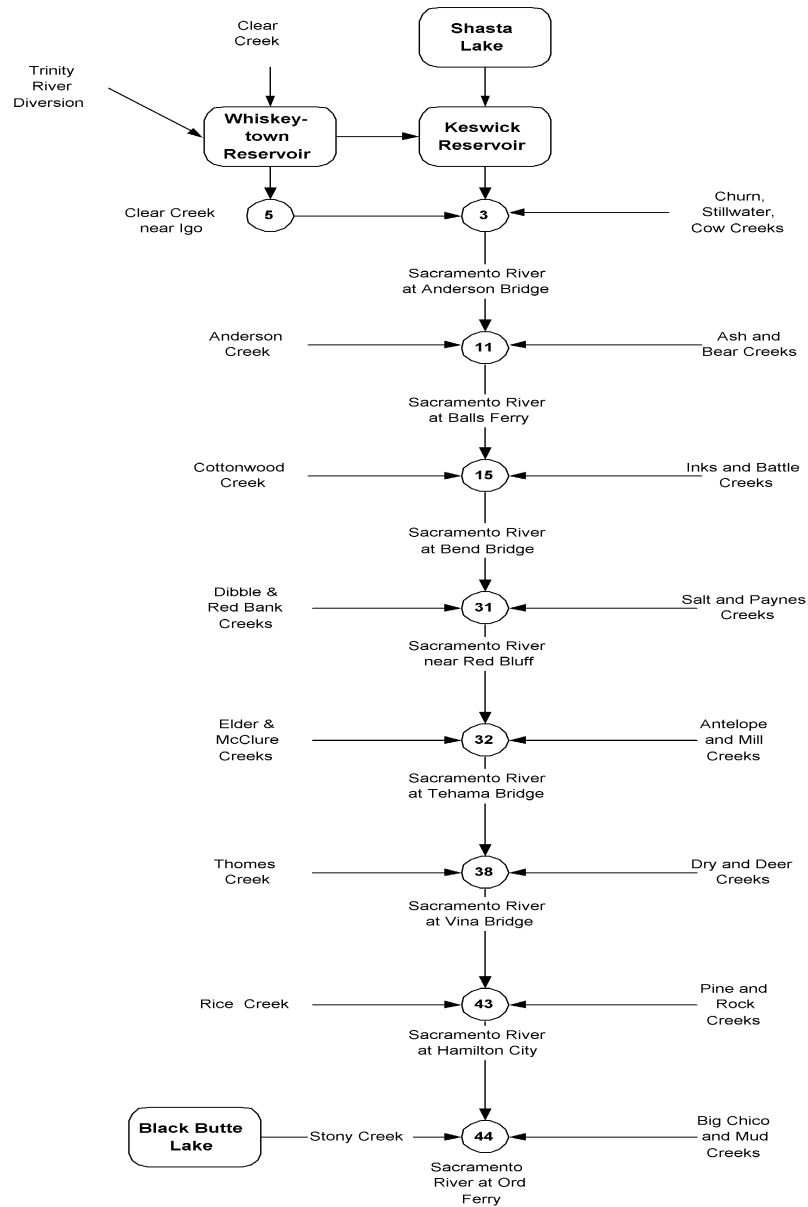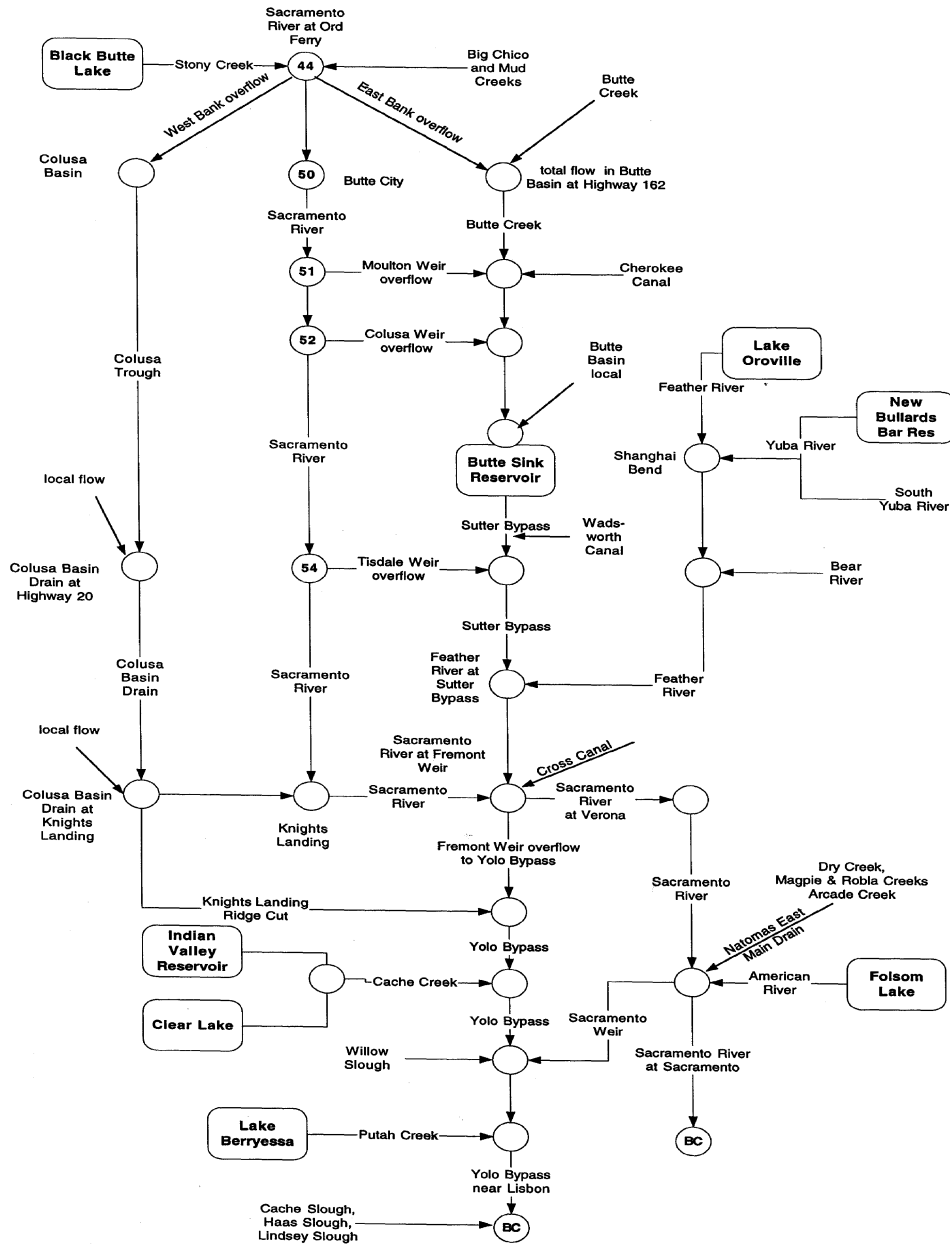
FIGURE   **1.**
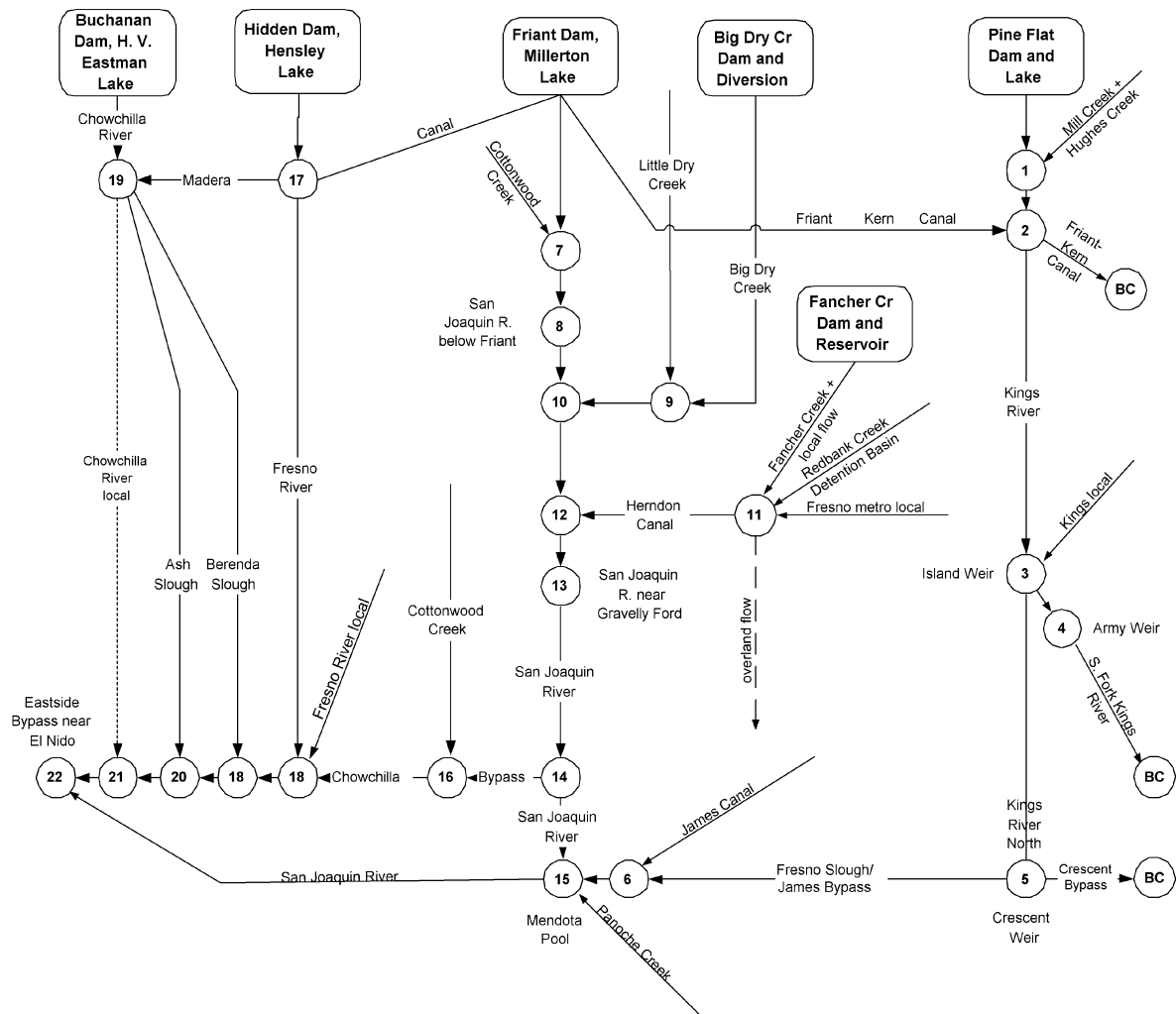
Sacramento River Watershed
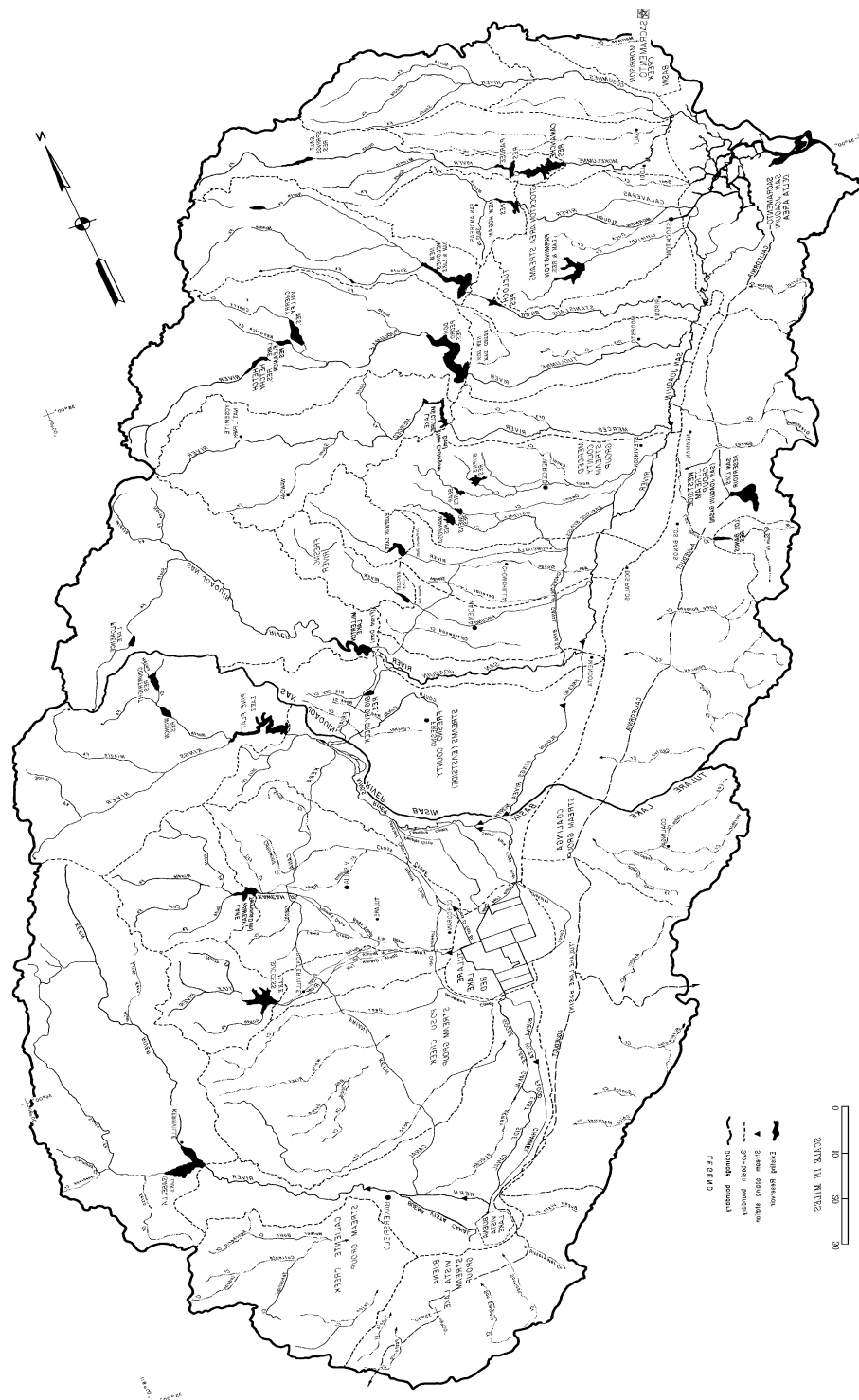
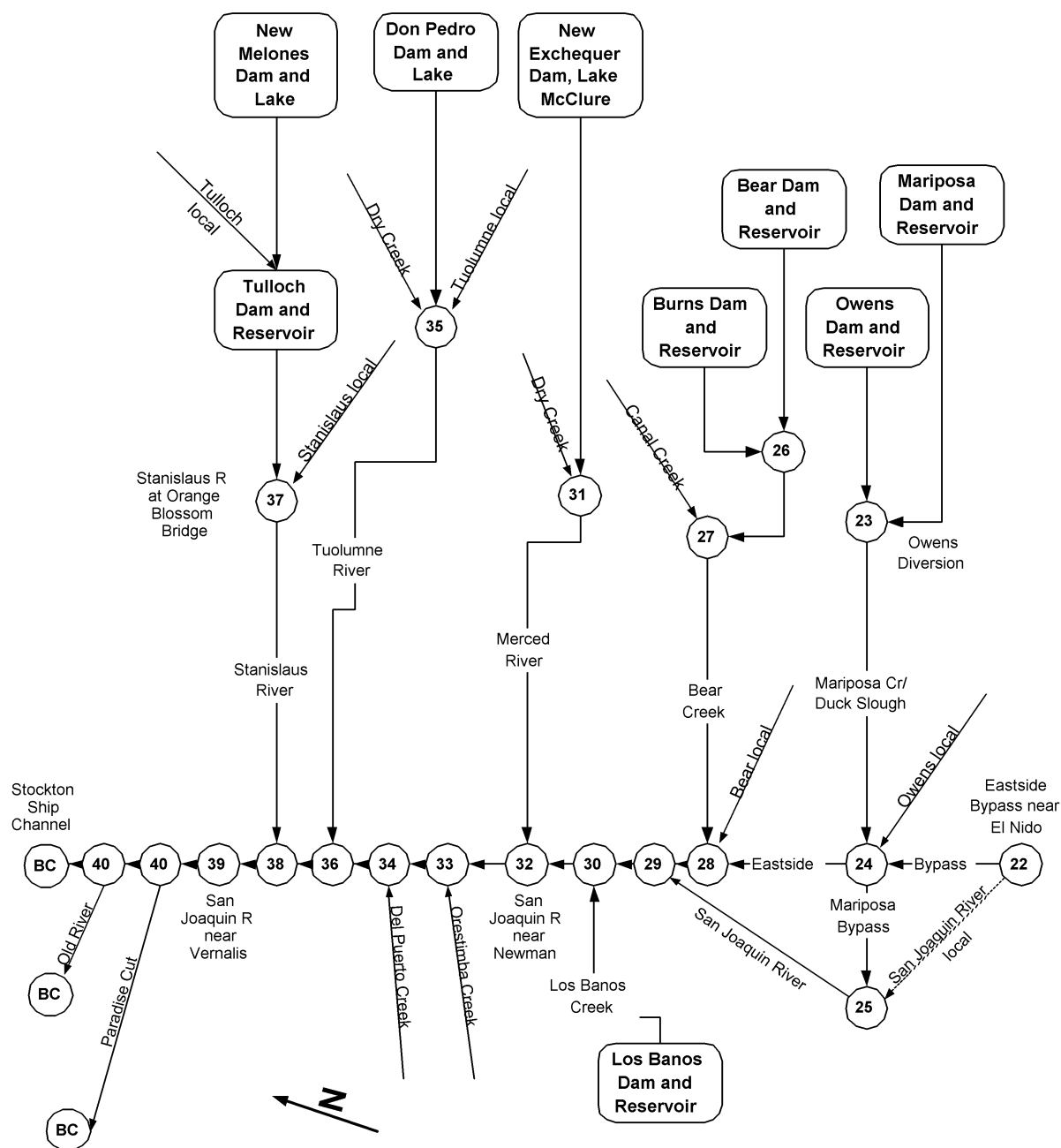**FIGURE 2. San Joaquin River & Tulare Lake Watersheds**

FIGURE 3. Schematic Diagram of Sacramento River System HEC-1 Model - Keswick to Ord Ferry
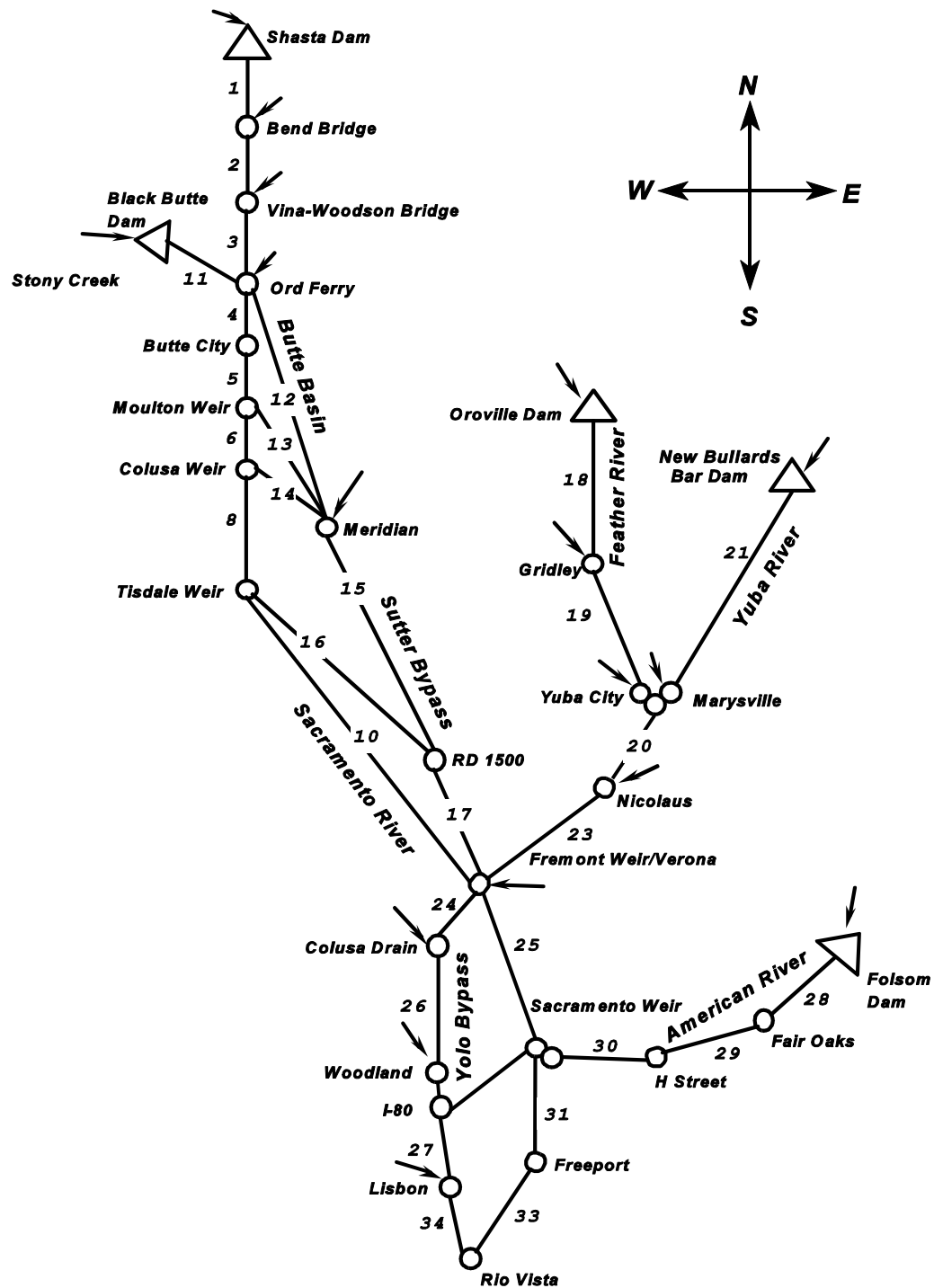
FIGURE 4. Schematic Diagram of Sacramento River System HEC-1 Model - Ord Ferry to Sacramento

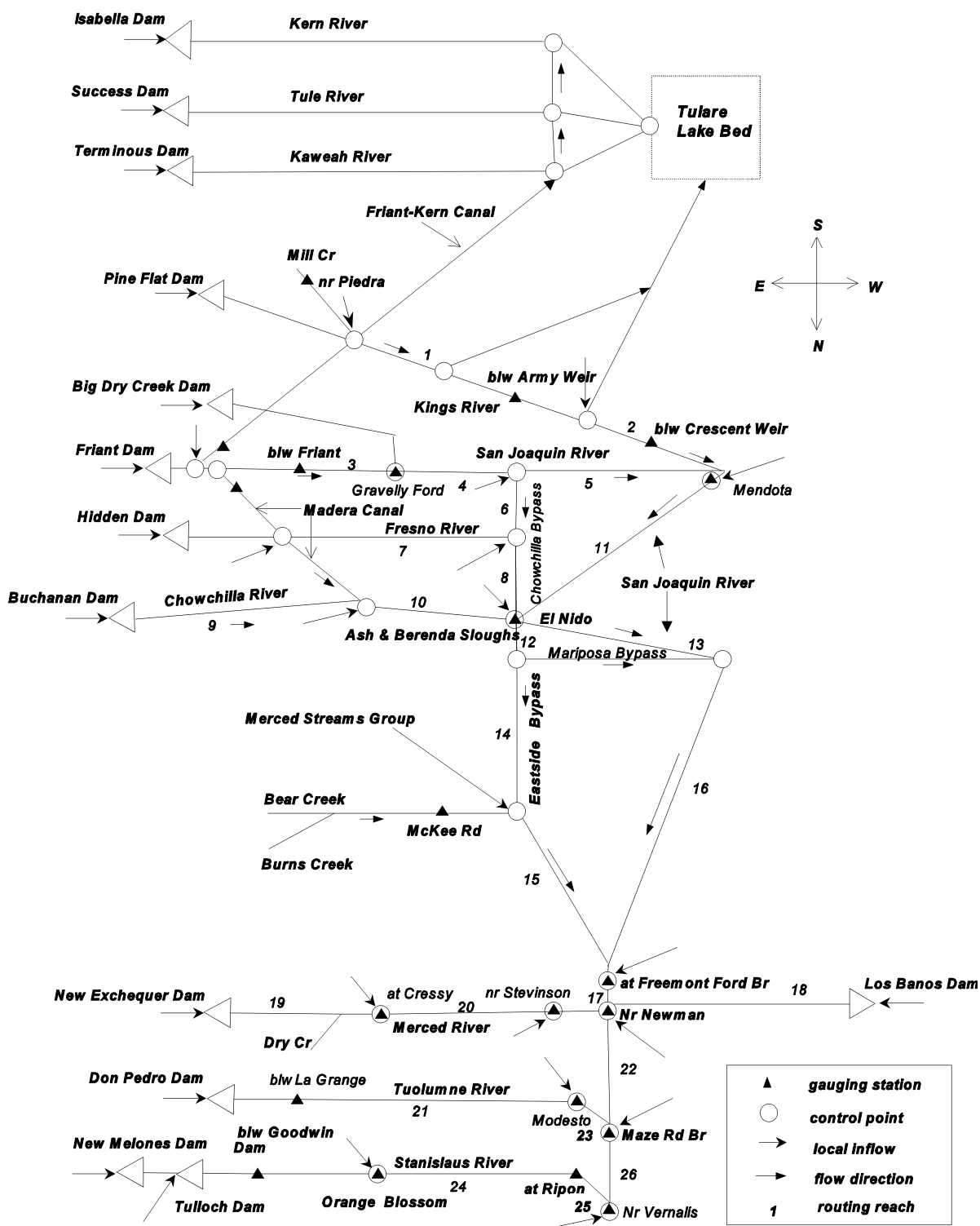**FIGURE 5. Schematic Diagram of San Joaquin River System HEC-1 Model - Friant to El Nido**

FIGURE 6.   Schematic Diagram of San Joaquin River System HEC-1 Model - El Nido to the Delta
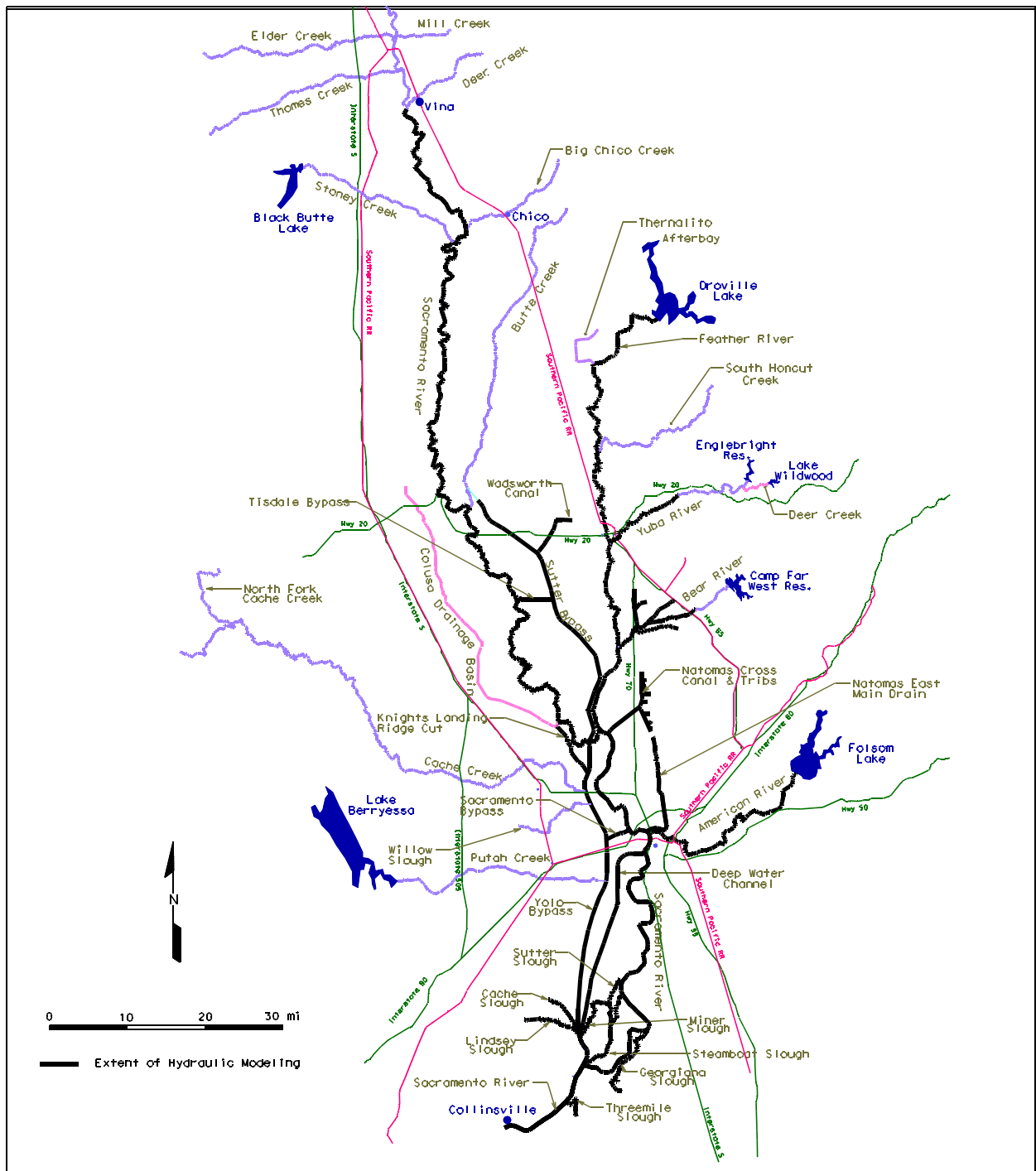
FIGU **RE**
7. **Sch**
ematic Diagram of Sacramento River Basin HEC-5 Model
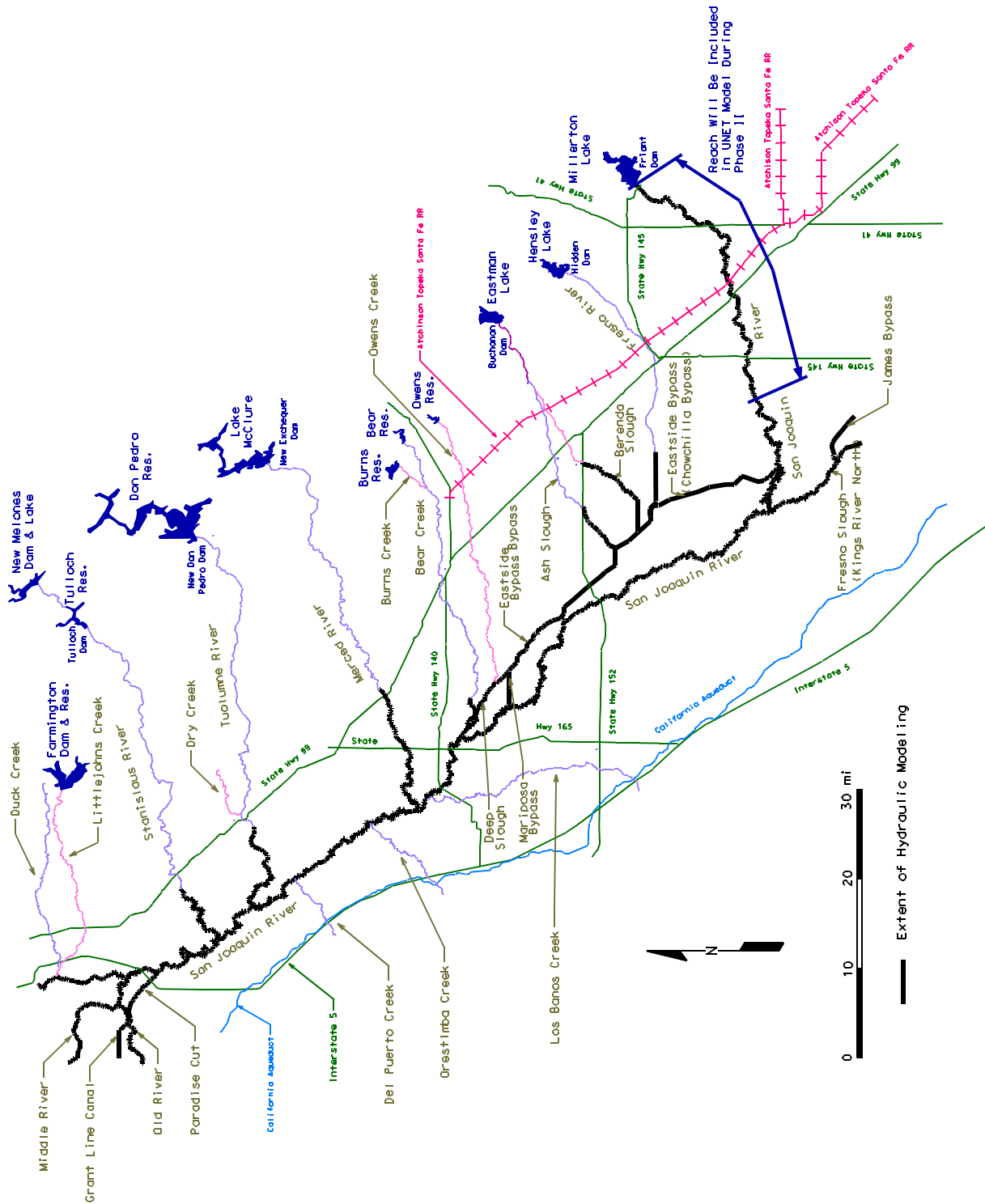
FIGURE 8.   Schematic Diagram of San Joaquin River Basin HEC-5 Model

FIGURE 9. Extent of Hydraulic Modeling in Sacramento River Basin

FIGURE 10. Extent of Hydraulic Modeling in San Joaquin River Basin